RESEARCH APPROACH

Work Plan/Experimental Design

The proposed work will be conducted with four phases as described below:

Phase I – Literature Review

The research team will conduct a comprehensive review of the final report of WHRP project # 0092-02-03 submitted by Weyers et al.[1]. The research team will also carry out a literature search, review, and analysis of papers, technical reports, and any other publications pertaining to the long term durability of aggregates since the inception of the previous study. The results of this effort will provide the research team with valuable information needed to accomplish the objectives of the study.

WisDOT has a database of results from a large number of standard aggregate tests performed over the years. The tests were performed on samples from various aggregate pits and quarries in the state. This database is of great value in ascertaining the impact of any proposed aggregate testing regime. This database will be obtained for detailed analyses in this research. Also, information on geological characteristics of each Wisconsin aggregate source will be compiled so that the test results can be categorized both by the aggregate source and its geologic characteristics.

Based on the current knowledge of the proposed research team regarding the aggregate testing performed since the completion of the Weyers et al.[1] study, it is anticipated that the works by Hossain et al.[10], White et al.[11], Rangaraju[12], Cuelho et al.[16], and Lang et al.[14] would also be of interest for detailed examination and analysis. Raw test data will be sought when such data are not directly available from published reports. Of particular interest would be the geological characterization (through petrographic analyses or otherwise) of the various aggregate sources tested by different researchers. An example is the work by Koubaa and Snyder[15]. Such data would be important with respect to comparisons with test results from similarly-characterized aggregate sources from Wisconsin.

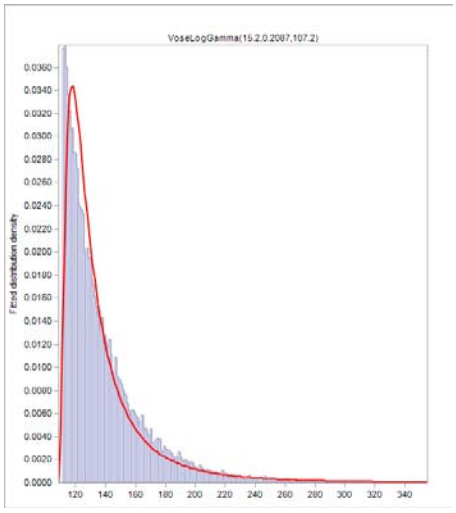
The research team will also contact state DOTs in the Midwest region with aggregate characteristics and environmental/climate conditions similar to Wisconsin. Mn/DOT is one example of an important agency to contact. The proposed research team (Titi et al.[7]) performed a comprehensive laboratory testing and evaluation program on 12 aggregate sources from Minnesota through a research contract with Mn/DOT. Therefore, the research team has contacts with Mn/DOT and experience in testing and characterization of aggregates. We will seek aggregate test databases similar to what WisDOT has compiled as well as the DOTs' research results on aggregate tests.

Phase II – Analysis of Existing Data and Interim Report

All data collected in Phase I will be synthesized and arranged in databases for statistical analyses. The following analyses will be performed:

1) The WisDOT database information on standard tests will first be fit into statistical distributions. For example, the L.A. abrasion test results (for the entire state as well as each aggregate source and aggregate type) will be analyzed using the ModelRisk

software program to find the best fit curve to the data (say lognormal, normal, beta,… distributions and their parameters). An example of a Log Gamma distribution fit to the heaviest 5% weight data for class 5 trucks in Wisconsin is shown below.



Also, the entire database will be used to develop statistical "copulas" between the different test results. This requires that we know the results of various tests on each aggregate sample. Copulas are used to develop multivariate statistical simulations. They are extensively used in the financial and insurance industries, but have been used in civil engineering as well. The proposed PI for this project is currently completing a CFIRE sponsored project on analysis of weigh-in-motion (WIM) truck data in Wisconsin. As part of that study, he has calculated statistical distributions for different axle weights and axle spacings for various truck classes for all 6 million trucks in the WIM database for one year. Similar copula analyses have been performed. The multivariate simulations using copulas allows estimation of likely percentages of "failure" for each aggregate source or type if a particular test regime is selected. For example, we could use the copula information to see what effect the test matrix proposed by Weyers et al. would have on a particular aggregate type (i.e. what percentage would likely be rejected if such a test regime is adopted). Similarly, data that may be obtained from other sources (such as Minnesota) can be analyzed if the aggregate types are similar to Wisconsin sources.

2) The Weyers et al.[(1)] test data will be analyzed using the multivariate logistic regression analyses. The analyses performed by Weyers et al. did not go beyond linear regression analyses, did not involve multivariate analyses, and did not include the test acceptance limits as a variable in Pass/Fail decisions. Therefore, a series of multivariate logistic regression analyses will be performed on the data. The objective of this effort would be to ascertain whether any of the new tests proposed (say Micro-Deval) can be correlated statistically to any standard test, or combinations of standard tests, when variable acceptance limits are used. Such an approach will statistically assess whether a newly proposed test (such as the Micro-Deval) is in fact measuring something new that is not currently being assessed using a combination of standard tests.

   In logistic regression, the test variables need not necessarily be numbers (continuous). They could be categorical (say pass/fail, good/bad/mediocre, etc.). By varying the acceptance limit for each standard test, the pass/fail outcomes of each test would change. Then, we can determine, through multivariate logistic regression analyses, whether the pass/fail outcomes of a new test can be statistically correlated, individually or in combination, to the pass/fail outcomes of standard tests (at different limits). If such a correlation cannot be found, then the new test is in fact a new way of testing these aggregates. It should, however, be emphasized that finding that a test is unique does not necessarily mean that it is a good indicator of long-term field performance. That would require analyses of data from field performance of each

aggregate, which at the present time does not appear to exist in a sufficient quantity to allow proper statistical inference. In this effort, we plan to find any such correlations, or lack thereof, between tests. The research team will have a choice of software programs to use for the logistic regressions. These include XLSTAT, Statistica, the "R software" (also called the "R Project"), and other general-purpose statistical software programs.

3) We will assess whether data regarding some tests are insufficient at this point to allow sufficient confidence in our statistical analyses. We would therefore propose additional testing to WisDOT for the Phase III of this study. It appears that WisDOT has interest in recycled aggregates and aggregates from industrial by-products. However, the data in the literature and in the Weyers et al. study (as currently known) seem to be less than adequate in some cases especially regarding industrial by-products and recycled asphalt pavement aggregates.

At the conclusion of Phase II, the research team will submit an interim report that includes the literature search and synthesis done in Phase I as well as the data analysis performed in Phase II and a recommended experimental plan for Phase III. The team will seek WHRP comments and approval before proceeding with the next phase.

Phase III – Laboratory Testing

It is anticipated that the team will conduct tests on 12 to 15 aggregate sources. The types of tests to be performed are expected to be similar to those performed by Weyers et al. The choice of samples will be made in consultation with WisDOT and aggregate samples will be obtained from WisDOT. The proposed tests may include the following (subject to any changes that may be necessary based on results from Phases I and II):

- Absorption (ASTM C127)
- Micro-Deval Abrasion (AASHTO TP58)
- L.A. Abrasion (ASTM C131)
- Aggregate Crushing Value (British Standard 813-Part3)
- Sodium Sulfate Soundness (ASTM C88)
- Unconfined Freezing and Thawing
- Percent Lightweight (ASTM C123)
- Concrete Freezing and thawing on selected samples (ASTM C666)

Phase IV – Data Analysis and Report

In this phase, the research team will incorporate the new dataset into the existing databases and repeat the analyses performed in Phase II incorporating the new data. Based on the results, the research team will assess whether any new tests, or combination of tests, would be warranted and assess the impact of such recommendations. To do that, Monte Carlo simulations using the best-fit statistical distributions for aggregate sources (calculated using the WisDOT database) and copula and regression information obtained from the Weyers et al. results and the new tests. The project Consultant (Statistician) will advise on, and review, all

aspects of planned statistical analyses before they are performed by the research team. The software program available to conduct Monte Carlo simulations is the "Crystal Ball" program. The proposed PI for the project has used this program in a number of previous and current research projects. This program will be used to determine the likelihood of pass/fail for different aggregate sources using the Weyers et al. test regime and any other test plan that may be recommended. For example, a possible outcome of such an analysis could be stated in such a form: "There is 80% chance that 10% of aggregates from this particular source would 'fail' based on the test regime proposed by Weyers et al. Similarly, probabilities for other percentage of 'failed' cases can be provided. This process will be coded into a MS Excel spreadsheet running the Crystal Ball Software. Such information will allow WisDOT to gage the impact of any new test program, and assess any major departures from current test outcomes.

The research team will then synthesize the results and submit a draft final report to WHRP for review and comments. We will also present the results to the Geotechnical TOC. After receiving the review comments, we will proceed to prepare the final research report. During the project, quarterly progress reports will be submitted as required by WHRP.

Anticipated Research Results and Implementation Plan

This project is anticipated to provide answers, based on analyses of existing and new aggregate test data, on whether the outcomes of any new tests (recommended by Weyers et al.) are , or are not, statistically correlated with current standard aggregate tests that are being performed routinely by WisDOT. If they are correlated, what are the statistical relationships between the standard tests and new tests? Additionally, what are the implications of proposed test regimes (such as those recommended by Weyers et al.) on the test outcomes from various aggregate sources for which statistical information is available?

The stakeholders or intended audience that the results of the research will most likely impact are WisDOT and various aggregate suppliers in Wisconsin. Potential impediments to implementation include costs of implementation. Activities necessary for successful implementation include incorporation into the Wisconsin construction specifications as required.

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